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Basic Instrumentation at NBS

A PROGRAM of research and development in basic instrumentation is now in its fourth year at the National Bureau of Standards. Under the general direction of W. A. Wildhack, Chief of the NBS Office of Basic Instrumentation, new applications of physical principles are being evaluated and applied to problems in measurement and control. Theoretical analyses are also conducted in various phases of instrumentation, and critical surveys are made of available instruments and techniques for types of measurement that are becoming increasingly important.

The NBS Office of Basic Instrumentation was established in 1950 to serve as a research, reference, and consultation center on problems of instrumentation for the laboratories of government and industry. Its program is sponsored by the Office of Naval Research, the Air Research and Development Command, the Atomic Energy Commission, and the National Bureau of Standards. While this program constitutes only a relatively small part of NBS activities, it represents an effort to utilize the Bureau's facilities and experience in the field of physical measurements to advance those techniques of measurement and control that are fundamental to progress in science and industrial technology.

Improved instruments for measuring basic physical magnitudes are vital to advances in the physical sciences and their applications. Yet until recently the problem of designing instruments to measure different quantities and for use under different conditions has been largely left to the individual scientist or engineer working in his particular technical field. However, it is coming to be more and more widely recognized that the problems met with in designing various kinds of scientific instruments have much in common and that the designer of an instrument for a specific purpose can often benefit from the experience gained by others with instruments built for quite unrelated purposes. In an effort to realize the advantages that would accrue from coordinated planning of research on instrumentation as a science in itself, the NBS Office of Basic Instrumentation was established. Under such a program, it has been possible to take advantage of ideas and developments originating in various technical fields that have a bearing on basic instrumentation problems.

The technical work of the Office of Basic Instrumentation has two principal objectives: (1) systematic analysis of available methods and devices in terms of their performance and characteristics, and (2) research on new applications of principles and materials leading to the development of instruments and techniques not now available. This program is carried out largely through the assignment of instrumentation research projects to those NBS laboratories that are best qualified to conduct research in the particular field of science involved. However, the Office of Basic Instrumentation also maintains a small laboratory staff of its own for investigation of special problems and a group of specialists in instrumentation literature who are developing a reference and consultation service to aid in the solution of instrumentation problems.

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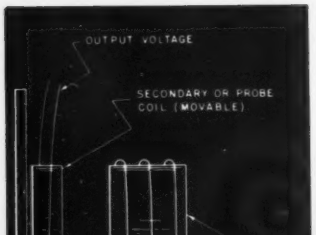
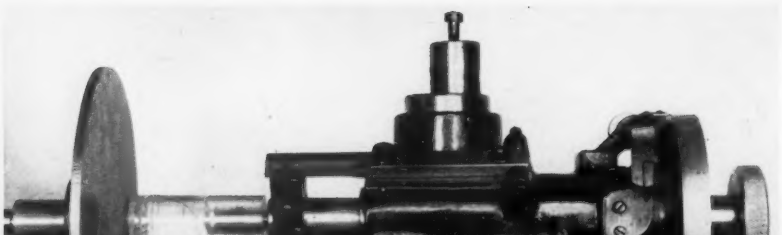




Schematic diagram (left) illustrates the principle of the mutual-inductance micrometer (right). This model of the micrometer employs two coils, a primary and a secondary. Alternating current fed into the primary induces current into the secondary, and the amount of this current varies with the distance of the secondary from a conductive shield. The thickness of a nonconductive medium between the secondary coil and a metal surface can thus be measured.

The various projects included in the technical program may be classified into four groups:

(1) Critical surveys of available instruments or techniques for certain types of measurement that are taking on increased importance.

(2) Projects for the theoretical or experimental evaluation of new applications of physical principles to *general* problems in measurement and control. Normally such projects are limited to a basic exploration of probable fruitful applications and do not involve development of specific instruments incorporating such applications.

(3) Projects for the new application of physical principles to *specific* problems in measurement and control.

(4) Projects for theoretical analysis and development in various fields of measurement, control, or handling of measurement data.

In the earlier phases of the program, experimental projects of the types described under (2) and (3) predominated, largely because technical personnel particularly suited for a number of such projects were available. However, as the program proceeded, it has been possible to place additional emphasis on projects under (1) and (4). In particular, survey projects have been initiated in a number of important areas.

Surveys

The critical surveys of various general types of instruments are designed to assist the engineer or scientists in making the proper selection of existing types of instruments for new applications as they arise or to aid him in combining various elements of known characteristics in the design of new instruments. Such surveys also provide the information needed for adequate planning of more specific instrumentation projects. Surveys of this kind now in progress include studies of millimicrosecond oscillography, dynamic pressure instrumentation, strain-gage recorders, voltage-sensitive devices, and analog-to-digital converters.

Large fluctuations in fluid pressure, often occurring at high frequencies, present an important problem in the design and operation of jet aircraft, rockets, and chemical plants. Recent needs, particularly in aeronautic and ordnance research, for making dynamic fluid-pressure measurements have indicated the practical necessity of a survey in this field. It is believed that an up-to-date compilation of significant techniques will be of great value to all workers faced with such problems. Thus far a bibliography of about 250 books, articles, and reports of various Government research laboratories, covering the period from 1920 to the present, has been assembled, and a broad outline has been prepared to guide an investigation of the literature. The present bibliography is to be extended, and individual articles are to be reviewed and summarized. The manufacturers' literature will also be reviewed, and some attempt will be made to evaluate instrument performance where data are available.

The survey of millimicrosecond oscillography has also progressed. Recent developments in radar, television, atomic physics, telemetering and other fields have greatly increased the need for oscillographic measurements in the time range below one microsecond. As a result, newer and faster oscillographs are being developed. Such instruments will also find applications in the study of electrical breakdown under steeply rising voltage surges—a subject of growing importance in insulation testing. A survey in this field is expected to be useful not only in the planning of new research but also for guidance in instrumentation problems concerned with the recording of high-speed transient voltages.

Although analog-to-digital converters are used in

a number of different applications and new types are being developed to meet new situations, the development and use of such devices has been hampered by the lack of a comprehensive picture of the requirements to be met and the techniques presently used to meet them. In an effort to bring widely scattered information on this subject together, data have been collected on analog-to-digital converters manufactured by commercial companies and on those now being developed by these companies and by Government agencies.

The survey of strain recorders, recently undertaken, has as its object the gathering of technical information that will aid in the selection of equipment for producing autographic stress-strain records of tensile tests. The use of recorders for this purpose has become standard practice in most materials testing laboratories. However, the recorders are supplied by manufacturers in a variety of forms, and there is little in the open literature to guide the user in the selection of equipment. There is even less information regarding the accuracy of recorders and strain gages. The results of this survey will be based on laboratory studies at NBS as well as on information obtained from other sources.

Specific Problems

Laboratory studies of more specific problems in instrumentation have resulted in a number of developments having broad potentialities for measurement or control. For example, a method [1] was developed which uses heavy water to determine the total water content of biological tissues, proteins, inorganic crystals, and other materials. Based on a spectroscopic measurement of the ratio of ordinary to heavy water in a solution containing the sample, the isotopic method is outstanding in the rapidity and convience with which it can be applied to a large number of samples.

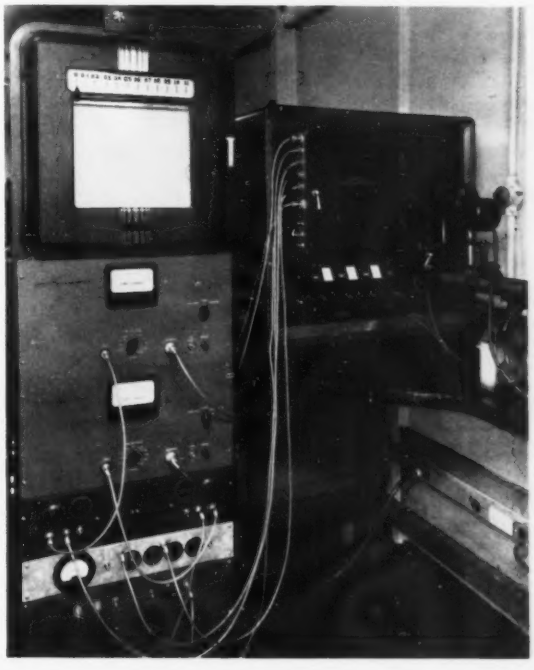
In another project of this kind, research on the wave properties of electrons has resulted in the development of an interferometer [2] that utilizes electron beams to produce interference fringes in much the same way as conventional optical interferometers use light beams. The NBS electron interferometer greatly extends the range of light interferometers used in the direct measurement of length. The instrument also constitutes an extremely sensitive device for measuring gradients of magnetic and electrostatic fields—analogous to refractive indices in optical interferometry—and provides a means for obtaining additional information on the wave nature of the electron. Other suggested applications of the method include studies of the energy levels in solids and an absolute determination of Planck's constant.

Spurious electrical signals, or "noise voltages", present a problem in many types of instrumentation work where cables are subjected to mechanical shock and vibration. They interfere with measurements of pressure in underwater explosion and air-blast research and with the determination of acceleration in shock and vibration studies. They also adversely affect the performance of crystal-type microphones, hearing aids, and phonograph pickups and of many other high-impedance devices in the fields of communication, measurement, and control. The mechanism of the noise generation was not generally understood and was often assumed to be somehow related to piezoelectric or converse electrostrictive effects, changes in the electrical constants of the cable, or separation of electrical charges by friction. Last year a detailed theoretical explanation was formulated for the generation of the spurious signals, and a low-noise instrument cable [3] was developed.

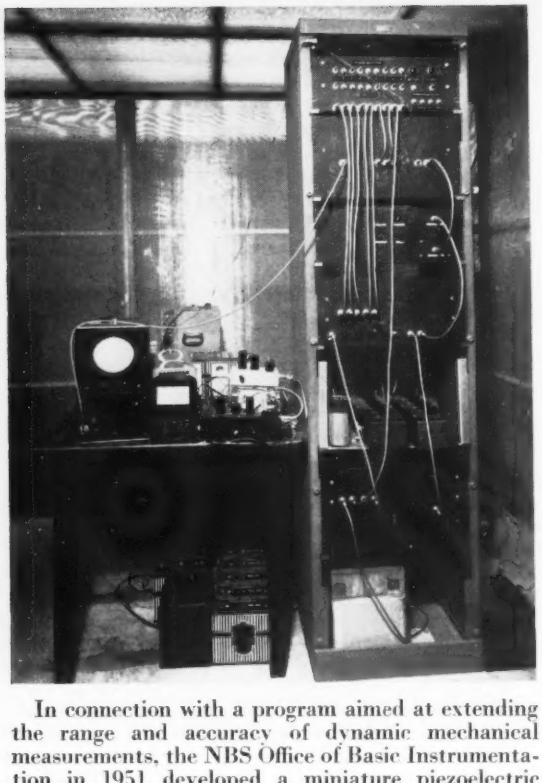
[1] Isotopic method determines water content, *NBS Technical News Bulletin* **36**, 145 (*October 1952*).

[2] Electron-beam interferometer, *NBS Technical News Bulletin* **37** 101 (*July 1953*); Electron interferometer by L. Marton, *Phys. Rev.* **85**, 1057 (*1952*).

[3] Noise-free instrument cable, *NBS Technical News Bulletin* **36**, 37 (*March 1952*).



Left: **Ramberg vacuum tube accelerometer, essentially a double diode with elastically supported plates on either side of the common cathode.** ***Right:*** **Apparatus used at NBS for low-temperature measurements of humidity by spectrographic means. The method utilizes the hydrogen excitation spectrum. The apparatus includes a grating spectrograph (right) and photomultiplier equipment (left) for recording of the spectra.**



The thermal noise thermometer, an instrument which determines temperature from the thermally generated electrical disturbance in an electronic circuit. Originally conceived and constructed at the University of Chicago, the noise thermometer has been redesigned by the Bureau in connection with its program in basic instrumentation. Amplifiers for the current from the temperature-sensitive element are at right. At left are a monitoring oscilloscope and an integrating circuit.

In connection with a program aimed at extending the range and accuracy of dynamic mechanical measurements, the NBS Office of Basic Instrumentation in 1951 developed a miniature piezoelectric accelerometer [4] for direct measurement of high-frequency vibrations. The device, which employed a barium titanate crystal as the compressive element, was extremely small but in many ways superior to other instruments used to measure mechanical vibration and shock. Further investigations of the barium titanate accelerometer, largely concerned with design characteristics and calibration methods, have continued. In the course of this work a model has been developed having exceptionally wide ranges of acceleration and frequency response (50,000 *g*, 100,000 cycles per second).

Research and development work on applications of pneumatic principles has resulted in a series or family of new instruments [5] based on gas flow at sonic velocity through nozzles. Utilization of these principles promises to provide improved instruments for the measurement of pressure, temperature, rate of flow, humidity, gas composition, mechanical displacement, and other quantities. A humidity measurement instrument has now been completed, providing a background of information that should be of value in the development of other instruments using the sonic flow principle.

[4] Miniature piezoelectric accelerometer, *NBS Technical News Bulletin* **35**, *141* (*October 1951*): A ceramic accelerometer of wide frequency range by Lawrence T. Fleming, *Instruments* **24**, *105* (*1951*).

[5] A versatile pneumatic instrument based on critical flow by W. A. Wildhack *Rev. Sci. Instr.* **21**, *251* (*1950*).

Other investigations of this kind that have been undertaken deal with such topics as the thermal noise thermometer, an electronic coating thickness gage, a carbon dioxide hypsometer, strain and displacement instruments, an ultrasonic velocimeter, feedback around image scanning systems, a phase sampling telemeter, the mutual inductance transducer, measurement of humidity by spectroscopic methods and microwave techniques, neutron spectrometer evaluation, and nucleonic instrumentation utilizing memory devices.

The carbon dioxide hypsometer represents an attempt to utilize the temperature of subliming solid carbon dioxide in equilibrium with its vapor at ambient pressure as a measure of pressure in upper air research. Several experimental models of this device have now been constructed and tested at pressures corresponding to altitudes up to 105,000 feet. The noise thermometer project was designed to evaluate the capabilities of the noise thermometer, originally developed at the University of Chicago, as an instrument for measuring temperatures on the thermodynamic scale and to investigate the suitability of the device for other temperature measurement and control applications. The ultrasonic velocimeter is expected to provide a simple, accurate method for measuring the speed of sound in liquids. A model of the device is now being used by the Navy to measure the speed of sound in water at various depths. The electronic thickness gage is designed to nondestructively measure the thickness of metallic coatings which differ from the basis metal in electrical resistivity or in magnetic properties. The gage is capable of working with nonmagnetic metals in applications such as the measurement of the thickness of silver or brass. The phase sampling telemeter, which utilizes a commutator-type sampling device, has been proposed as a system that may offer improvements over present telemetering systems for certain applications in accuracy, reliability, complexity, weight and size of components, and power requirements. The project on strain and displacement instruments involves work on high range and high temperature types of strain gages as well as the design and construction of improved models of the Ramberg vacuum tube accelerometer,[6] originally developed by NBS in 1946 for acceleration measurements in aeronautical work.

The work on image scanning systems is a study of the application of two-dimensional linear and nonlinear feedback in optical-electronic systems using cathode-ray tubes. Contributions to research may

[6] The improved Ramberg vacuum-tube accelerometer, *NBS Technical News Bulletin* **34**, *180* (*December 1950*).

result from solutions of nonlinear partial differential equations by this technique. Practical results may also be derived from its use as an aid in the recognition of patterns, such as the matching of fingerprints, automatic reading of printed or written matter, or possibly in weather prediction from synoptic maps.

An investigation has been conducted to determine the characteristics of the mutual inductance micrometer,[7] originally developed by NBS in 1947, as a transducer for various applications. An effort has been made to determine the influence of a large number of factors on the performance of a mutual-inductance transducer so that the optimum design for any specific use can readily be chosen.

In 1950 NBS developed a recording microwave refractometer[8] of high sensitivity that can continuously sample and record the dielectric constant of a stream of air or other gas. This instrument is now being investigated to determine its potentialities for use as a humidity standard. In another project, the Office of Basic Instrumentation is studying the possibility of utilizing the hydrogen excitation spectrum for absolute humidity measurements at low temperatures.

Because the neutron has no electric charge, the measurement of neutron energies is a problem quite different from that of electron, proton, or alpha-particle energy measurements. Thus far, methods that have been employed for this purpose have been quite varied in principle. The work on neutron spectrometer evaluation will involve a summary of characteristics of neutron spectrometers now in existence and an evaluation of proposed designs for new types. The project on nucleonic instrumentation will be concerned with the development of fast memory-tube-type pulse-height analyzers for nuclear research. It will also attempt to extend the use of memory tubes to other types of nuclear instrumentation. Another project in this field that is now being planned will include the construction and absolute calibration of a standard slow-neutron flux free of gamma rays and the development of instruments and techniques for intercomparison of unknown fluxes with this standard flux.

The projects described above, while not a complete listing, are typical and serve to indicate the scope of the work carried on by the NBS Office of Basic Instrumentation. Continual modification of the program and its objectives may be expected as the science of instrumentation develops and new instruments and measurement techniques become available.

For further information, see Is there a science of instrumentation? by E. U. Condon, *Sci.* **110** *339 (1949);* Operational aspects of instrument design by Churchill Eisenhart, *Sci.* **110** *343 (1949);* Instrumentation in perspective by W. A. Wildhack, *Sci.* **112** *515 (1950);* New tools for research by W. A. Wildhack, *Sci.* **114** *No. 2962 (1951);* and A program of research and development in basic instrumentation by Frank L. Thomas, *Monthly Research Report of the Office of Naval Research (January 1952).*

[7] Electronic micrometer, *NBS Technical News Bulletin* **34**, *137 (October 1950).*

[8] Recording microwave refractometer, *NBS Technical News Bulletin 34, 45 (April 1950).*

Versatile Photometric Goniometer

A goniometer of unusual versatility and precision has been devised by T. H. Projector and associates of the NBS photometry and colorimetry laboratory for use in the Bureau's photometric studies of aircraft and other lighting equipment. Designed for use on a 100-foot photometric range, the NBS goniometer is constructed for maximum rigidity and convenience and in such a way as to minimize errors due to backlash and torsion.

Goniometers used to measure the angular position of a light source on general-purpose photometric ranges must meet severe requirements. Test equipment may vary in weight over a wide range, and the distribution of weight and bulk may be quite variable. Yet a high degree of accuracy is required. The NBS goniometer was specially designed to combine accuracy with flexibility in order to accommodate the many types of photometric measurements made on the Bureau's 100-foot range and the great variety of equipment studied.

Conventional goniometers of this type ordinarily have two axes of rotation at right angles. Such goniometers may be divided into those having a fixed vertical axis and those having a fixed horizontal axis. Occasionally goniometers are also constructed in which cone angles are measured about one axis and polar angles are measured about the other axis. The new NBS goniometer has three possible axes of rotation and can be used as any one of the three types of goniometers.

Of the 3 axes of rotation, only 1, which measures horizontal angles, is permanently fixed. Of the other 2 axes, both of which may be rotated, 1 measures "horizontal" angles while the other measures "vertical"angles. In any given set of measurements, only 1 of the 2 horizontal angle rotations is used, the choice being dependent on the desired goniometric geometry or on the mounting requirements of the test equipment.

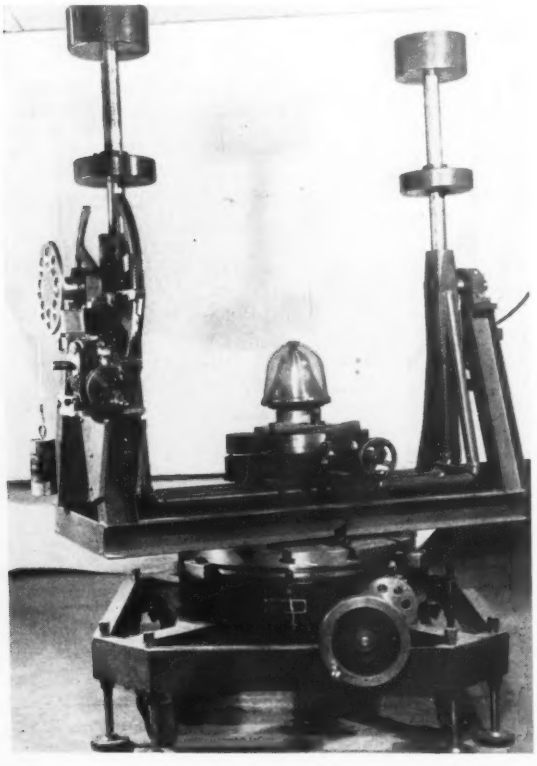
The horizontal angle rotations are obtained with rotary tables of the type used on machine tools, and the vertical angle rotations are obtained by means of two U-frames mounted on the lower table and supporting the upper table. The lower rotary table, 25 inches in diameter, is mounted on a heavy welded base and supports an outer U-frame made of welded iron channels. The second U-frame, constructed from lengths of iron pipe welded together, is mounted within the outer U-frame. This inner frame may be rotated about a horizontal axis extending through ball bearings set on pedestals at the tops of the arms of the outer frame. The upper

rotary table, upon which test equipment is usually mounted, is set at the bottom of the inner U-frame. T-slots in the 15-inch surface plate of this table aid in the mounting of equipment. The scales on the micrometer drives are graduated at 0.1-degree intervals on the upper rotary table, 0.05-degree intervals on the lower rotary table, and 0.01-degree intervals on the drive for the inner U-frame.

The handwheel drive for rotation of the inner U-frame is linked to the frame by a gear reducer, a pinion, and a large sector gear. A pair of fixed counterweights is attached to the ends of tubular shafts on each arm of the inner U-frame to balance the frame about its axis of rotation. In addition, a pair of adjustable weights permits balancing of the frame with test equipment mounted in place, and a constant torque is supplied by a small weight suspended from a pulley connected to the frame axis.

To balance the inner frame after the test equipment has been mounted on the rotary table, the frame is disengaged from the drive and then freely rotated until the arms are horizontal, in which position the balancing weights can be adjusted easily and balance determined accurately. With the inner frame balanced and the small weight suspended from the pulley, the frame is subjected to a constant torque of about 4 pound-feet at all settings of the "vertical" angle.

For most photometric work the upper rotary table is used for "horizontal" angle measurements. This means that the axis of the horizontal angle measurements rotates as the vertical angle setting is changed. However, where it is necessary that the axis of horizontal angle measurements remain fixed, the lower rotary table is allowed to rotate and the other table does not turn on its axis. Rotation of the lower table has also been found useful occasionally when the equipment mounted for study is too bulky to clear the arms of the inner frame.



For cone angel measurements the inner U-frame is rotated into the position where its arms are horizontal and the beam from the test equipment projects horizontally through the open end of the U-frame toward the photometer. From this position of the inner frame, cone angles are set by rotation of the inner frame, and polar angles are set by rotation of the upper rotary table.

Backlash and variable torque errors have been greatly reduced in the new NBS goniometer by the adjustable balancing arrangement and the constant torque device. In conventional goniometers, which lack balancing arrangements, backlash errors are minimized by rotating the goniometer in one direction only during a traverse. However, when such a goniometer is rotated through a vertical angle, there may be considerable variation in the torque loading. Under these conditions, even when rotation is in one direction only, backlash errors may be large and may vary considerably from test to test.

Although backlash is the most usual source of error in photometric goniometry, errors due to variable torsion may sometimes occur in parts subjected to torsional stress. Errors of this type have been kept to a minimum in the NBS goniometer by rigid welded construction of the inner frame.

To evaluate the accuracy of the NBS goniometer, angular intervals indicated by the goniometer were compared with those measured by a transit mounted on the upper rotary table in place of a test unit. No error greater than 0.03 degree in the measurement of angular intervals up to 90 degrees was found with either of the rotary tables. Errors in the measurement of vertical angles with the inner U-frame drive system were found to vary with angular interval from a maximum of 0.02 degree in a 1-degree traverse to a maximum of 0.10 degree in a 90-degree traverse.

For further technical details, see Versatile goniometer for projection photometry, by T. H. Projector, *Illuminating Engineering* 48, *192* (*1953*).

Goniometer designed for use in photometric studies of lighting equipment. The fixed axis is that of the lower rotary table, attached to the heavy welded base. An outer U-frame of welded iron channels is mounted on the lower table; an inner U-frame is mounted within the outer frame. The inner frame may be rotated about a horizontal axis extending through the top of the arms of the outer frame. A third axis of rotation is provided by the upper rotary table, which is set at the bottom of the inner frame. Test equipment is usually mounted on the upper rotary table. A handwheel drive (left) rotates the inner U-frame. Fixed and adjustable weights on the arms of the inner U-frame permit balancing the frame with test equipment mounted in place; a constant torque is supplied by the small weight (left) suspended from a pulley.

Improved Refractometer

An improved refractometer for the rapid and precise measurement of index of refraction has recently been developed at NBS by Oscar H. Grauer of the Bureau's glass laboratory. With the Grauer refractometer the index of refraction of specimens of glass or some other optical materials can be determined with high accuracy in a matter of minutes. Costly and time-consuming grinding and polishing operations, normally required when index-of-refraction determinations are made with other refractometers or spectrometers, are eliminated.

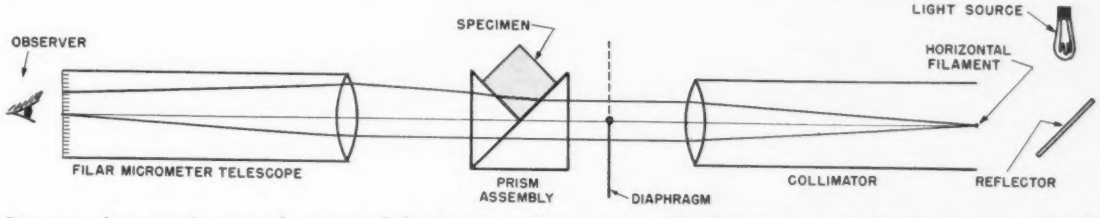
The instrument consists of a light source, a horizontal filament, a collimator, a diaphragm, a pair of 45-degree–90-degree cemented prisms forming a 90-degree hollow at the upper half and a parallel plate at the lower half, a filar micrometer, and a telescope. All the components are centrally alined along a common horizontal axis.

To determine the index of refraction of a piece of glass with the Grauer refractometer, the sample is simply cut with a 90-degree edge—no grinding or polishing is needed—and fitted into the 90-degree hollow of the cemented prism assembly. An immersion liquid having the approximate refractive index of the sample is used as a contact liquid between the sample and the prism. The observer sees two images of the illuminated filament; the lower half of the optical system produces a direct image, and the upper half of the system gives an image that has passed through the glass sample and been refracted. Either image can be blocked out by the use of the diaphragm. The separation of the upper image from the lower image is a measure of the index of refraction of the sample, and its magnitude can be determined with the filar micrometer. Calibration of the micrometer in terms of index of refraction is a simple matter. Highly accurate readings are much more readily obtained with the filar micrometer arrangement than with the graduated goniometer circle used in other refractometers.

The glass used for the prism assembly corresponds roughly in index of refraction to the sample being measured; by substitution of different prism assemblies different ranges of index can be covered. Indices of refraction of most commercial and optical glasses lie between 1.50 and 1.70. Each prism assembly can be used satisfactorily over a range of about 0.02, so that 10 to 12 sets will cover the necessary refractive index range. With homogeneous accurately cut samples and contact liquids matching the refractive index of the sample to 0.002, an accuracy of ± 0.00002 can be obtained. Certified immersion liquids are available commercially.

The glass sample, cut with a 90-degree angle, fits into a prism assembly (center). Looking into the telescope (left), the observer sees a double image of an illuminated filament. (Filament, light source, and collimator are at the right.) The separation between the two images varies with the index of refraction of the glass sample and is accurately measured by means of a filar micrometer that is part of the telescope.

Because of its combination of speed and precision, the refractometer is well suited to production control and research, as well as to the general determination of refractive constants of transparent substances. For instance, the refractometer has been used at the Bureau to provide a very sensitive check on the uniformity of optical glass being produced in a continuous-melting process. Samples are taken at frequent intervals and their refractive index rapidly measured; deviations from the desired composition or from optimum melting conditions are quickly detected. In annealing studies, where it is necessary to use very small samples so that equilibrium is quickly attained, refractive index measurements can easily be made to the indicated accuracy.



Drawing showing the optical system of the Grauer refractometer. The lower image of the filament seen by the observer passes through the lower part of the prism assembly and is not refracted. The upper image passes through the specimen and is refracted by an amount that varies with the index of refraction of the specimen.

Above: **Set-up in 10-million-pound testing machine, showing calibration procedure for 3-million-pound dynamometer. The device is loaded against three previously calibrated one-million-pound dynamometers. Note the electrical indicators on tables.** *Left:* **3 million-pound dynamometer with protective cover removed, revealing some unique features. Note parallel- and lateral-bonded wire strain gages mounted on column which is flared out at top and bottom to provide larger bearing areas.**

THE DEVELOPMENT of load calibrating devices of unusual size and capacity by NBS will permit the standardization of the largest materials testing machines in existence. The four NBS 3-million-pound-capacity compression dynamometers recently completed can accurately measure forces up to 12,000,000 pounds, or 6,000 tons. Prior to development of these dynamometers, which make use of attached wire-resistance strain gages as a part of their load-indicating systems, the highest load which could be accurately measured was approximately 2,500,000 lb. To do this required the simultaneous use of a considerable number of calibration devices (such as proving rings) of 200,000- and 300,000-lb capacity. It is estimated that a testing machine can now be calibrated to 10,000,000 lb by means of the new dynamometers in about one-fourth the time and at about

High Capacity Load Calibrating Devices

NBS dynamometers for calibrating multimillion-pound testing machines

half the cost formerly required to calibrate it to 2,500,000 lb.

The Bureau has for many years maintained a program to provide means of verifying the accuracy of tension and compression testing machines. These machines, widely used by industrial plants and laboratories, vary in size from small devices for testing small samples of rubber, textiles, plastics, and similar materials up to the huge machines capable of crushing a steel girder or a concrete cylinder several feet in diameter. Typical examples of these machines are the 4,000,000-lb machine at the University of California and 5,000,000-lb machines operated by the Department of the Navy in Philadelphia, Pa., and the Bureau of Reclamation at Denver, Colo. NBS has long had in its laboratories at Washington, D. C., a machine with a capacity of 10,000,000 lb, believed to have the largest capacity of any testing machine in the world. It is important to know that the test results obtained with these machines, large or small, are correct.

High-capacity testing machines are both important and necessary to an engineering research program. One reason is that mechanical properties of materials as determined from tests of small specimens do not always give a complete picture of what may be expected from a structure fabricated from large rolled sections or forgings. The strength of the material of a large I-beam, for example, may vary across its section; and the mechanical properties of a large forging may vary with direction in the forging, etc. It has been the experience of research engineers that the soundest approach to the solution of this problem is actual application of service loads to full scale specimens which have been fabricated from the same type of materials that would go into the real structure. This means that in the case of such structures as welded ship hulls and aircraft fuselage and wing components the loads required will be very great.

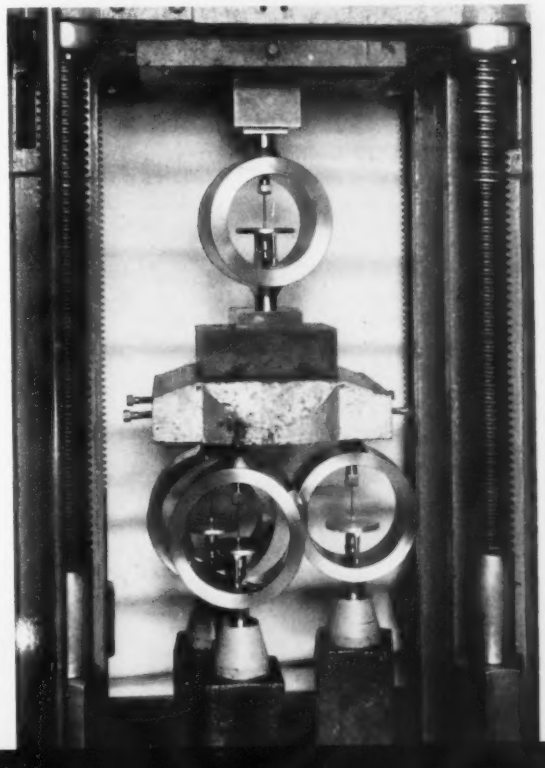
Still another reason for emphasis on testing full-scale units is the fact that failure of such structures in service is sometimes due not to lack of strength in the material but rather to points of high stress. These critical stress areas are caused by designs which include sharp angles or notches introduced into the structure during machining or welding. Points of high stress may operate in various ways: a complicated shape welded together may shrink as it cools in such a way that parts of the structure are stressed almost to failure before any external load is applied; or a notch cut in an airplane wing hinge may concentrate stresses 2 or 3 times as great as the average computed stress. It is impossible to reproduce, in a small scale model, the effects of welding stresses or machining notches.

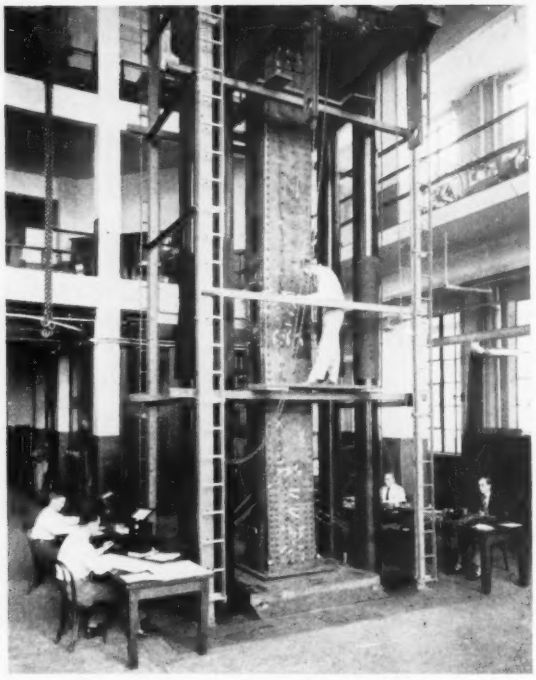
The structural engineer is thus forced to conduct his research on examples of the full structure. Here he finds himself in a world of stern reality in which he must apply loads ranging from a minimum of a few hundred thousand pounds up to 5 or 10 million pounds.

In order that the results obtained in research of this type may be considered reliable and intercompared with results from different laboratories, it is necessary to control the accuracy of the testing machines. It is a simple matter to calibrate smaller machines by use of proving rings, but the calibration of the larger machines presents definite obstacles. Proving rings are made in capacities up to 300,000 lb; and although it is possible to calibrate above this limit by simultaneous loading of several rings (the method has been employed up to about 2,600,000 lb.), the process is costly and difficult.

Both government and industry look to the Bureau for leadership in the field of load calibration. The

A 200,000-pound-capacity proving ring being calibrated by loading against three 100,000-pound rings. Each of the smaller rings has been calibrated by dead weights.





Believed to have the largest capacity in the world, the NBS 10-million pound testing machine has provided engineering data on full-scale structural units ranging from welded steel girders to aircraft components to structural building elements. This experimental arrangement is for the study of the effects of perforation (or "cut-outs") on the strength of a steel of the type used in the Calcasieu River at Lake Charles, Louisiana.

first proving rings were invented by H. L. Whittemore and S. N. Petrenko of the NBS engineering mechanics laboratory about thirty years ago, and the Bureau has since provided a standardization service for load measuring devices for the entire country.

About 1940 the bonded wire strain gage became a working reality. The gage consists of a grid of fine wire cemented to the surface of a specimen. As the material of the specimen becomes strained under load the wire is likewise strained, or stretched, thus changing its electrical resistance. The change of resistance bears a simple relationship to the strain in the specimen and can be measured by suitable instruments.

The possibility of utilizing a uniformly stressed column with gages attached in such a way as to respond to the average strain on the column seemed a most promising solution to the problem of measuring loads of a million pounds or more. It was known that a device designed in this fashion could work to a much higher load in proportion to its own weight than could a proving ring; and, since the output of the strain gages would be correlated directly against load, no assumption need be made as to the gage factor. Accordingly, Dr. Lyman J. Briggs, then Director of the Bureau, instituted a project under the direction of B. L. Wilson and D. R. Tate of the engineering mechanics laboratory to develop load measuring devices of this type that would permit calibration to capacity of the largest testing machines. The objective was to design devices that would achieve the stability and accuracy of the proving ring, about one-tenth of one percent.

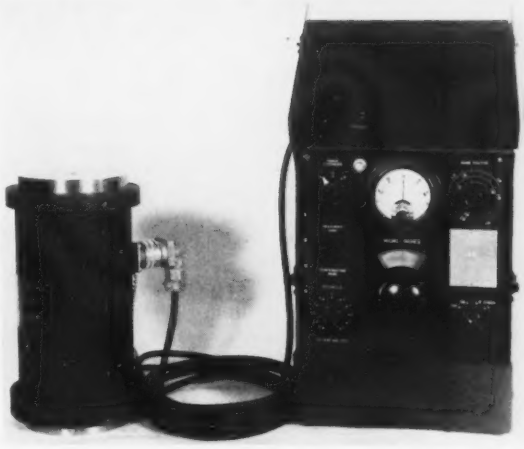
The NBS program has now reached the point where 8 devices have been completed and calibrated, 4 with a capacity of 1,000,000 lb. each, and 4 with a capacity of 3,000,000 pounds each. Together the latter four offer a total capacity of 12,000,000 lb., more than enough to calibrate to capacity the largest testing machine in existence.

The use of wire strain gage devices for the measurement of load is by no means new; such devices were being produced commercially for weighing and balancing airplanes at the time the Bureau started development of the compression dynamometer. The unique features of the NBS devices are the application of the method to measurement of very high loads, the procedure used to calibrate the devices, and the particular feature of design in which the highly stressed column is flared out at top and bottom to integral ends having bearing surfaces of relatively large area. This design results in relatively low stresses between the device and the bearing blocks through which they are loaded by the testing machine. Thus accurate and reproducible results are obtained. The dynamometers are used in conjunction with an electrical indicating instrument, modified from the ordinary commercial strain indicator for strain gages. The electrical instrument is used to measure the small shift of balance of a bridge circuit composed of elements of resistance wire strain gages attached to a highly stressed portion of the device. By mounting some of the gages in such a way as to measure the compressive strains parallel to the load axis of a compression column and other gages to measure tension strains caused by the lateral expansion of the same column, a bridge having a maximum output and good temperature compensation can be formed.

The NBS devices are calibrated by extension of the method developed for large proving rings which exceed the capacity of the Bureau's 111,000-lb. dead-weight testing machine. In calibration of a 300,000-lb. ring, the ring is first calibrated as far as possible by dead weights. It is then set up in a testing machine and loaded against three 100,000-lb. proving rings, which have been previously calibrated to capacity by dead weights. The load exerted by the machine is transmitted through the 300,000-lb. ring and shared equally by the three 100,000-lb. rings. All 4 rings are read at once and the load is computed from the readings of the 3 smaller rings. In this way a calibration may be secured to 300,000 lb. and the errors of the testing machine do not affect the result.

In extension of the process, four large rings are calibrated by this method and then used together to calibrate a 1,000,000-lb. wire strain gage dynamom-

NBS 1 million-pound dynamometer (and electrical indicating instrument) developed for extension of standardization of large testing machines into million-pound range.



eter. Three or four of these, in turn, are used to calibrate the 3,000,000-lb. device.

Although there are many problems yet to be solved in this type of instrumentation, the present devices appear to be satisfactory in the work done to date at NBS. On the basis of widespread interest among materials engineers, it seems likely that dynamometers of the new type will be used to calibrate large testing machines, in government laboratories, universities, and other research laboratories at a reduced cost and a saving of time.

For further technical details, see The application of resistance wire strain gages to high capacity load calibrating devices, by D. R. Tate, *Symposium on wire strain gages, NBS Circular 528 (in press).*

Reclamation of Asbestos

Simple, effective procedures for reclaiming asbestos from discarded pipe insulation have been developed by E. W. Zimmerman of NBS. Extraneous material is removed from the asbestos cloth by chemical treatment, and the cleaned cloth is reduced to fiber form in a paper-pulp beater. The recovered asbestos is unchanged chemically, with little or no shortening of the fibers. It appears well suited to further use as electrical and heat insulation, for making asbestos paper, and as a filler in molder plastic compounds.

Because of its incombustibility, strength, and low conductivity, asbestos is widely used in roofing shingles, fireproof paints, stove and building insulation, heat-resistant aprons and gloves, and brake linings. However, present supplies of this raw material are critically short. As large quantities of molded asbestos and asbestos cloth are used to insulate pipes of various kinds in naval vessels, the Navy Bureau of Ships requested NBS to study the possibilities of reclaiming asbestos insulation discarded during the repair or refitting of ships.

To aid the Bureau in its investigation the Navy supplied samples of discarded pipe insulation. These were of three general types: asbestos cloth, asbestos-cotton cloth, and a molded pipe lagging having asbestos fiber as a filler and magnesia cement as a binder. Some of the asbestos-cotton cloth had glass strands woven into the yarns. Other samples of this cloth were painted or were covered with a cement-like material containing magnesia. The problem thus reduced itself to two parts: first, removal of the extraneous material and, second, reduction of the cleaned yarns or cloth to fibrous form.

For applications where flexibility is desired, such as asbestos paper or cloth, chrysotile asbestos is used. Although this type of asbestos is quite satisfactory for insulating heated pipes, it loses its water of constitution and becomes brittle when heated to about 800° C. It was therefore necessary to develop procedures that would reclaim the asbestos fibers without the use of excessively high temperatures.

It was found that asbestos or asbestos-cotton fabrics other than those containing paint can be freed of adhering cement by first treating with 5-percent hydrochloric acid and then rinsing. Fabrics painted on one side are treated with alkali instead of acid to remove the paint as well as the cement. This is accomplished by boiling in 5-percent sodium hydroxide solution for 15 to 30 minutes, followed by a preliminary rinising, a warm wash with a synthetic detergent to remove the paint pigment, and a final thorough rinsing.

Removal of cotton from the cleaned cloth is best effected by the use of heat, but the process requires rather careful control to avoid loss of the water of constitution and consequent embrittlement. Thin layers of the material are heated in a muffle furnace at a temperature between 400° and 450° C. The time necessary to burn out the cotton in this temperature range depends largely on the equipment used. After removal of cement, paint, and dirt, the cloth is reduced to fiber in a rotary food blender or in a paper pulp beater.

The fabric containing glass strands was composed of very short asbestos fibers. Although an acid wash followed by rinsing removes most of the cement from this material, removal of the dirt is difficult without loss of some of the short asbestos fibers, which float off with the dirt. The recovered product contains glass fibers intermixed with the short asbestos fibers and thus will probably be of limited use.

The molded insulation yielded only 15 percent of fiber, and this was highly contaminated with foreign materials. Thus, recovery of asbestos from such material does not seem very practicable. In any case, use of the fibers recovered from the molded insulation would have to be limited to magnesia-cement components and similar products.

HIGH-RESOLUTION MICROMANOMETER

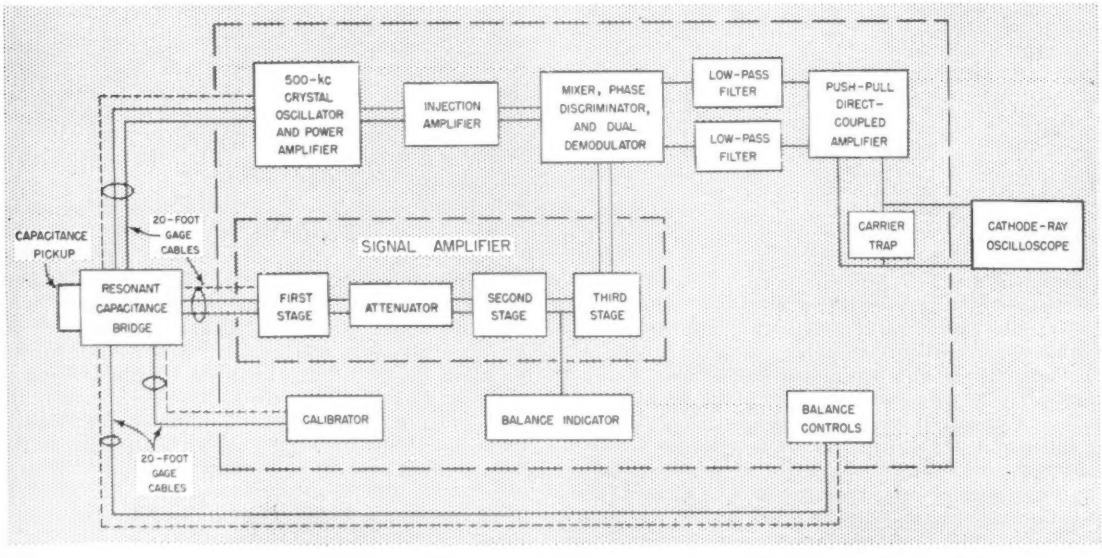
A highly sensitive micromanometer, designed to measure differential pressures as low as 0.03 micron of mercury (0.00003mm of Hg or 1.6×10^{-5} inch of water) with resolutions of the order of 0.001 micron of Hg, has recently been developed by T. A. Perls, W. H. Kaechele, and D. S. Goalwin. The development is the result of a research program conducted by the Bureau's Office of Basic Instrumentation and sponsored jointly by the Office of Naval Research, the Air Research and Development Command, and the Atomic Energy Commission. The NBS micromanometer utilizes a thin diaphragm combined with a capacitance-type pick-up and a resonant-bridge carrier system to detect pressure differentials 100 to 1,000 times smaller than those detected by previous systems. Besides measuring static differential pressures, the micromanometer can sense with an accuracy of better than 2 percent pressures varying at rates up to 20 cycles per second.

A major limitation in the field of basic instrumentation has been the difficulty of sensing very small displacements accurately. This problem arises, for example, in various instruments that utilize diaphragms as a means for converting small changes in pressure to mechanical displacements. For instance, the extreme sensitivity of a thin metal diaphragm separating two pressure-tight cavities can be utilized as an accurate temperature control. Here minute changes in temperature cause a pressure differential between the two cavities, which, in turn, makes the diaphragm deflect. Another class of utility is in the measurement of dynamic pressure changes as experienced in blasts and underwater explosions. One technique [1] currently employed utilizes a relatively thick, small-diameter diaphragm and results in high accuracy by means of the sensitivity of a resonant-bridge carrier system, a system similar to the one used in the NBS micromanometer.

The micromanometer developed by the Bureau consists of a 3-inch diameter corrugated diaphragm made of brass sheet 0.001 inch thick and mounted in a shallow cylindrical cavity. The diaphragm is placed so as to divide the cavity into two pressure-tight chambers. An insulated electrode passes through the top of the cylinder to become one side of a variable capacitor; the flexible diaphragm forms the other side of the capacitor, which then has a nominal capacitance of about 20 micromicrofarads. Changes in either temperature or pressure within one of the cavities will cause the diaphragm to flex and move. This motion varies the electrode-diaphragm spacing; and, consequently, the capacitance of the system is changed by a small amount. Over the mechanical operating range used the displacement of the diaphragm varies directly as the pressure differential, and the changes in capacitance also vary linearly with the displacement of the diaphragm. The electronics portion of the NBS micromanometer has sufficient range of sensitivity to respond, with an accuracy of 2 percent, to full-scale changes between 0.005 and 0.2 micromicrofarad above and below the

[1] A new condenser-type pressure gage by T. A. Perls, *Report No. 625, The David W. Taylor Model Basin (June 1949)*.

Block diagram of resonant-bridge carrier system. The NBS micromanometer forms the fourth arm of a resonant capacitance bridge composed of three other capacitors. The driving power for the bridge is a 500-kc crystal oscillator, and the frequency response of the electronic system is flat within ±1.5 percent from 0 to 50 kc.

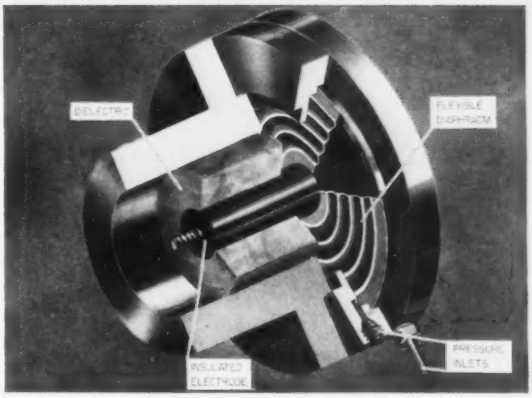


20-micromicrofarad capacitance of the system.

The electrode-diaphragm-cavity section of the NBS micromanometer forms the fourth arm of a resonant capacitance bridge composed of three other capacitors, each of which has a low multimegohm resistance in parallel with it. The parallel resistances tend to make negligible changes in leakage resistance of the capacitors. The driving power for the resonant capacitance bridge is derived from a 500-kilocycle crystal oscillator; a frequency response flat within ± 1.5 percent from 0 to 50 kc is one of the useful characteristics of the carrier circuit. A small difference in pressure between the two cavities in the micromanometer, which causes a deflection of the diaphragm and thus a change in the capacitance of the system, upsets the balance of the resonant capacitance bridge. The 500-kc output from the bridge varies in amplitude according to the magnitude of the pressure change and in phase (zero or 180 deg), depending on the direction of the deflection. The signal-modulated carrier from the bridge is amplified and then mixed with the unmodulated carrier from the 500-kc driving oscillator in a special mixer, phase discriminator, and dual demodulator stage. The two signals add or subtract according to the direction of the original diaphragm displacement.

The output of the mixer is a replica of the capacitance change in the resonant capacitance bridge and, consequently, a measure of the differential pressure. The unwanted 500- and 1,000-kc harmonics in the output are filtered, and the resulting low-frequency or d-c potential is applied through a d-c amplifier directly to the plates of a cathode-ray oscilloscope or to any other suitable indicating or recording device. The response of the system—both mechanical and electrical—over the pressure range used is sufficiently linear to require the calibration of pressure differential versus voltage output only at "zero" and one other point within the operating range, usually chosen near "full scale." The resulting readings can be made with an accuracy of 2 percent.

The extremely low pressure differentials that can be measured with the NBS micromanometer created the problem of obtaining a device sensitive enough to calibrate the instrument. The calibrating device that appeared to offer the most advantages was the Ascot-Casella micromanometer,[2] an instrument that uses a torsion balance to measure the difference of pressure-area products in two bells floating on kerosene. An important characteristic of this instrument is that an increase in volume or temperature introduced into the system connected to one of the bells causes it to move upward. Simultaneously the bell on the other side of the balance is lowered with a resulting reduction in volume under it and an increase in pressure in the system connected to it. The difference in pressure between the two bells—both pressures having increased—is smaller, by a large factor, than the pressure differential that would have resulted had the system been rigid. In the system used in calibration of the NBS micromanometer, the above factor was found to be 13,200.



Cut away drawing of pressure probe for NBS diaphragm-type, capacitance-type micromanometer. A corrugated diaphragm, 3 inches in diameter and 0.001 inch thick, forms the common wall between two pressure chambers. An insulated electrode passes through the top of the micromanometer to become one side of a variable capacitor. The flexible diaphragm forms the other side.

During the calibration the NBS micromanometer is placed in the measuring system of the Ascot-Casella micromanometer so as to be affected by the same pressure changes. The contribution of the "live" volume of the cavity of the NBS micromanometer was measured and found to be about 1 percent of the total effect. A hypodermic syringe is used to inject air into the system and thereby to cause an unbalance. The resulting differential pressure is read simultaneously with both the Ascot-Casella and NBS micromanometers and provides the required calibration data. For pressures below 1.5 micron of Hg the precision of a single reading on the Ascot-Casella micromanometer is not sufficient for an accurate calibration. Therefore, the calibration of oscilloscope deflection versus pressure differential must be interpolated from previous data (for pressures between 0 and 1.5 μ of Hg) of changes in pressure produced by changes in volume introduced by the syringe. It is thus possible to calibrate the NBS micromanometer over a pressure range of from 0 to 0.07 μ of Hg. The mean deviation of the calibration points from a straight line was of the order of 0.001 μ of Hg, the same order of magnitude as that of the error in reading the change in volume produced by the syringe. The curve also indicated that the hysteresis of the system—the difference in readings for equal values of increasing and decreasing pressures—is smaller than or approximately equal to the resolution of the NBS micromanometer (0.001 μ Hg).

A micromanometer using a capacitance-type pickup and resonant-bridge carrier system depends for its high resolution on the area and thinness of the diaphragm and on the sensitivity of the electronic circuit. Deflections of the order of one millionth of an inch (full scale) and capacitance changes of 0.005 micromicrofarad are involved. In resolution and

[2] Ascot-Casella micromanometer by H. R. Hindley, *J. Sci. Inst.* **24**, 295 (1947).

sensitivity the NBS micromanometer shows a decided improvement over other devices also designed to measure static and semistatic differential pressures with the aid of diaphragms. Some prior developments in this field include micromanometers that use an unbonded-wire strain gage [3] or a mutual inductance pickup [4] to detect the displacements of the diaphragm. The best resolution that has been obtained with these systems is about 0.1 μ of Hg.

Although designed to measure differential pressures, the NBS micromanometer can be modified to measure absolute pressures below 1 μ in apparatus where the presence of mercury, oil, or other liquid is undesirable. This may be accomplished either by maintenance of a high vacuum on one side of the diaphragm or by the sealing of one side at a high-vacuum level. The micromanometer should then be particularly useful for calibration of ionization gages. The characteristics of the instrument are such that it could possibly be used also as a secondary standard of low pressure in the range from 0.001 to 1 μ of Hg.

For further technical information about the resonant-bridge carrier system, see U. S. Patent 2611021, Resonant bridge circuits; *and* Measuring minute capacitance changes by G. W. Cook, *Electronics* **26,** *105 (January 1953).*

[3] A highly sensitive differential manometer, *NBS Technical News Bulletin* **32,** *11, 132 (November 1948).*

[4] Diaphragm-type micromanometer with electronic pickup, *NBS Technical News Bulletion* **34,** *10, 137 (October 1950).*

Flowmeter Correction

In the February 1953 issue of the Technical News Bulletin, there appeared a description of an electronic flowmeter. It has since been learned that a flowmeter was described in 1950 by Hess, Swengel, and Waldorf, which used the same system of switching reversible transducers to obtain a measure of flow: "Ultrasonic Method for Measuring Water Velocity," W. B. Hess, R. C. Swengel, S. K. Waldorf. AIEE Miscellaneous Paper 50–214, October, 1950.

Other references which should have been included are the following: (1) "Electromagnetic Flowmeter," A Kolin, U. S. Patent 2,149,847 (1939); (2) "Preliminary Report on Temperature Measurement by Sonic Means," Earl W. Barrett and Verner E. Suomi, Journal of Meteorology, August 1949, p. 273; (3) Oskar Rutten, German Patent 520,484, November 1928; (4) J. W. Gray, U. S. Patent 2,534,712, December 19, 1950, filed November 30, 1945; and (5) B. O. Stroule, British Patent Specification 623,022, May 11, 1943.

It is regretted that these references were not known at the time the Technical News Bulletin article was prepared, and that this article gave the erroneous impression that all features of the development were new. The features that appear to be novel are (1) rapid switching, (2) synchronized rectifications, and (3) the use of transducers mounted externally.

Lightning Resistance of Porcelain Insulators

Integrated with the electrical standards program of NBS is an investigation of techniques for determination of the performance of electrical equipment under extreme conditions. One phase of the investigation, dealing with the action of pin-type porcelain distribution insulators during high-intensity electrical storms, has resulted in the development of a method for measurement of the ability of these insulators to withstand lightning strokes. The method involves the generation of voltages similar in waveform to those appearing on lightning-struck power lines and the discharge of these potentials across an insulator at rates up to 11 million volts per microsecond. The study, sponsored by the Rural Electrification Administration, was conducted by J. H. Park and H. N. Cones of the NBS staff.

In some rural areas it is not economically feasible to protect the high-voltage distribution lines against direct strokes of lightning. In most cases a lightning stroke flashes over the insulators; and after the momentary ground has been cleared, the line operates normally. Occasionally, however, an insulator is punctured during a lightning storm and shatters. In other instances, after being struck by lightning, the insulator has all outward appearances of intactness but actually has been punctured through the porcelain from a point under the tie wire or line conductor to the supporting pin. During a dry period the insulator performs its designated function; but during a rain storm the water creates an electrical path over the surface of the wooden crossarm on which the insulator is mounted, and the punctured insulator is unable to prevent a ground.

Field experience has indicated that most of the failures occur on certain insulator designs that have previously performed favorably under the standard laboratory investigating methods currently in use. One insulator manufacturer,[1] however, has been using a measurement technique that consists in subjecting the insulator to a very steeply rising voltage surge (rates of rise from 3,000 to 10,000 kilovolts per microsecond). When exposed to the voltage surges, the insulators that will not withstand lightning strokes puncture and shatter. Because the methods for producing and measuring such steep-front voltage surges have not been standardized, NBS has been requested to make an investigation that would ultimately lead to the adoption of some standard technique.

The experimental program conducted by the

[1] *The Ohio Brass Company independently employs techniques similar to those designed by NBS to evaluate the performance of its insulator products. Comparable results have also been obtained.*

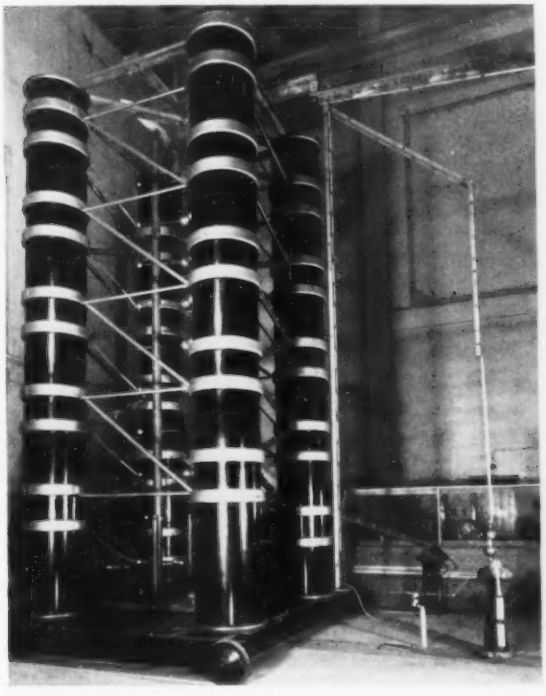
Bureau was carried out in two phases: (1) a suitable measurements method or procedure was designed, and (2) the method was applied to various types of new insulators so that a comparison between the NBS procedure and other existing techniques could be made. The voltages required to simulate the effects of lightning strokes were obtained from a surge generator consisting of twenty ⅓-microfarad capacitor units, each rated at 100 kilovolts. The major objective was to obtain a voltage wave rising abruptly from zero at a very high and constant rate until insulator flashover occurred. The arrangement chosen was a parallel circuit with 10 series-connected capacitors forming each arm. With this technique it is possible to obtain a high rate of voltage rise and maintain a maximum voltage output of 1,000 kilovolts by reduction of the effective internal impedance of the generator. A 10,000-ohm resistor connected to ground and in parallel with the capacitor bank serves to keep the external discharge circuit at a fairly low voltage until the current at the gaps of the capacitors has increased to several amperes. An external resistance of 70 ohms is connected between the top of the generator (20 feet above the floor) and an output discharge gap. The other side of the gap joins a voltage divider, used to measure the applied potential, and the insulator to be investigated. When the current in the capacitor bank rises to a sufficiently high value, the air in the gap breaks down and the steeply rising voltage is applied across the insulator and the divider. The average rate of voltage rise on the front of these waves is 7,000 kilovolts per microsecond, but by shorting out of the internal resistance of the generator and by removing the external resistance, rates of voltage rise up to 11,000 kilovolts per microsecond have been obtained.

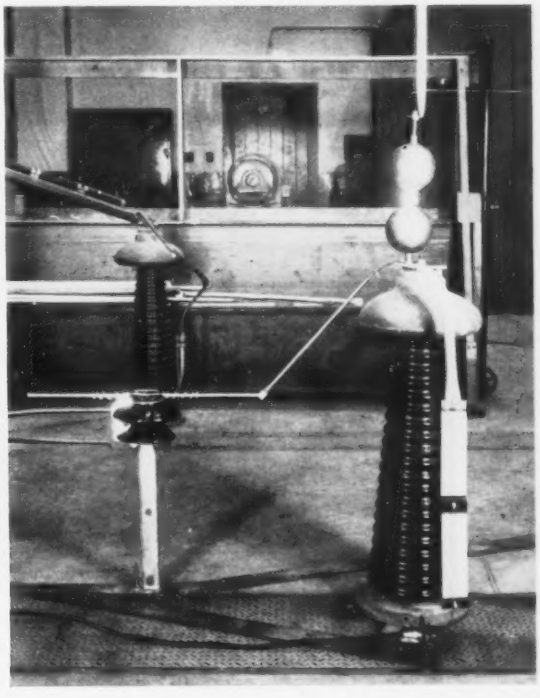
During the preliminary investigations no punctures were obtained on the first application of a surge voltage to an insulator, even when the steepest rates of voltage rise were used. However, several insulators punctured after repeated applications, some with rates of voltage rise as low as 3,000 kilovolts per microsecond. Consequently, in the method finally selected eight equal voltage surges are applied at 20-second intervals to each insulator.

Further studies of measurement techniques and procedures utilizing steep-front voltage waves are now in progress at the Bureau. Before standards can be adopted by the industry, however, the various laboratories of the country must agree on experimental procedures for generation and measurement of the necessary voltage surges.

For further technical details, see Puncture tests on porcelain distribution insulators using steep-front voltage surges, by J. H. Park and H. N. Cones, *AIEE Technical Paper 53-257 (April 1953). This article is scheduled to appear in the August (1953) issue of Power Apparatus and Systems (AIEE).*

Left: **Surge generator (left) voltage dividing network (right) used by the Bureau to determine the ability of a porcelain distribution insulator to withstand lightning strokes.** ***Right:*** **Voltages are discharged across a gap (upper right) at a high rate (11 million volts per microsecond) and are applied simultaneously to the insulator (left) and a voltage divider (right), to which the measuring circuit is connected.**





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SINCLAIR WEEKS, *Secretary*
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A. V. ASTIN, *Director*

September 1953 Issued Monthly Vol. 37, No. 9

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Publications of The National Bureau of Standards

PERIODICALS

Journal of Research of the National Bureau of Standards, volume 51, number 2, August 1953 (RP2432 to RP2439, incl.). Annual subscription $5.50.

Technical News Bulletin, volume 37, number 8, August 1953, 10 cents. Annual subscription $1.00.

CRPL–D108. Basic Radio Propagation Predictions for November 1953. Three months in advance. Issued August 1953. 10 cents. Annual subscription $1.00.

RESEARCH PAPERS

Reprints from Journal of Research, volume 51, number 2, August 1953. Single copies of Research Papers are not available for sale. The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will reprint 100 or more copies; and requests for the purchase price should be mailed promptly to that office.

RP2432. Heat capacity, heats of fusion and vaporization, and vapor pressure of tetrafluoroethylene. George T. Furukawa, Robert E. McCoskey, and Martin L. Reilly.

RP2433. Hydrothermal preparation of some strontium silicates. Elmer T. Carlson and Lansing S. Wells.

RP2434. Ultraviolet spectral radiant energy reflected from the moon. Ralph Stair and Russell Johnston.

RP2435. Phase equilibria in the system MgO-TiO_2. L. W. Coughanour and V. A. DeProsse.

RP2436. Pairs of normal matrices with property L. Helmut Wielandt.

RP2437. Heat capacity of gaseous hexafluoroethane. John S. Wicklund, Howard W. Flieger, Jr., and Joseph F. Masi.

RP2438. Effective circuit bandwidth for noise with a power-law spectrum. Philip R. Karr.

RP2439. Penetration of X- and gamma rays to extremely great depths. U. Fano.

CIRCULARS

C529. Electrodeposition research. Proceedings of the NBS Semicentennial Symposium, containing 22 papers. $1.50.

C537. Table of dielectric constants and electric dipole moments of substances in the gaseous state. A. A. Maryott and F. Buckley. 20 cents.

C541. A spectrophotometric atlas of the $^2\Sigma^+ - {}^2\Pi$ transition of OH. A. M. Bass and H. P. Broida. 20 cents.

PUBLICATIONS IN OTHER JOURNALS

Note on the indentation of heavy leather. Robert B. Hobbs. J. Am. Leather Chemists Association. (University of Cincinnati, Cincinnati 21, Ohio). 68, No. 6, 349 (June 1953).

Plastic electrets and their applications. H. H. Wieder and Sol Kaufman. Electrical Engineering (33 West Thirty-ninth Street, New York 18, N. Y.) 72, No. 6, 511 (June 1953).

Accurate radio-frequency microvoltages. M. C. Selby. Electrical Engineering. (33 West Thirty-ninth Street, New York 18, N. Y.) 72, No. 6, 515 (June 1953).

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